§7. Studies on Cooling Performance of Vacuum Windows for High Power Millimeter Waves

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Development of vacuum window assembly which is capable of transmitting high power (~1 MW) millimeter waves is one of the key technical issues to realize the CW ECH system for LHD. For this purpose, we designed a new gas-cooled single-disk window assembly and tested its cooling performance.

Figure 1 shows a schematic structure of the gas cooled single-disk window assembly used in the present experiment. The circular disk (~2 mm thick) is made from silicone nitride composite (SN-287) which has a relatively low loss-tangent. It is held between two annular stainless steel holders (aperture size is 88.9 mm). The cooling gas (dry nitrogen at a pressure of several kg/cm^2) is ejected through 24 nozzles (1 mm diameter) drilled with equal distance around the aperture.

We conducted two experiments ; (1) a microwave transmission experiment using a 84 GHz Gyrotron, (2) a simulation experiment using an electrically heated film resistor (0.12 mm thick) attached to the disk surface as a heat source. The surface temperature of the disk was measured by an IR camera (exp. 1) or a radiation thermometer (exp.2).

In the experiment (1), microwave power with 130 kW and 30 s duration was transmitted through the window. The incident power density was estimated to be ~7 kW/cm^2 at the disk center. Without gas cooling, the peak temperature continued to increase during 30 s RF pulse (thermal runaway) and reached to 320^{o}C. Whereas, it was completely saturated at 124^{o}C by the gas cooling with 465 l/min flow rate. In this case, the heat transfer coefficient estimated from the decay time of the temperature after the end of RF pulse was 0.1 kW/cm^2, which was about 1/3 of the coefficient obtained with the liquid (FC-75) cooled double-disk window system.

In the experiment (2), we examined how the cooling performance depends on the number (N) and arrangement of the gas-ejecting nozzles. Figure 3 shows the temperature rise at the center (ΔT) as a function of the gas flow rate per nozzle (q) for different N. The temperature rise is strongly reduced with increase of q till q~5 l/min, but further increase of the gas flow does not lead to significant reduction of ΔT. This data also shows that the cooling is more effective for smaller N when the total flow rate is kept constant. This means that gas flow speed is a key parameter which determines the cooling performance. Measurement with a hot-wire anemometer indicated that the flow speed was 50 m/s for q=5 l/min. As for the arrangement of gas injection nozzles, higher cooling performance was obtained when they were distributed around the aperture with equal spacing.

We think that by applying this method to an elongated Brewster angle window, we can realize a window system needed for high power CW operation.

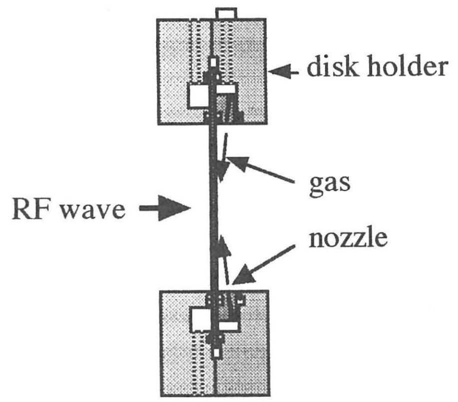

Fig. 1 Gas-cooled vacuum window assembly.

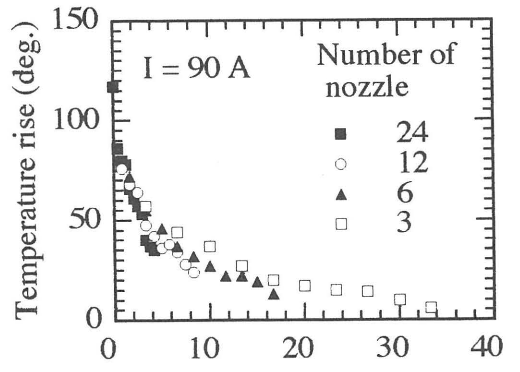

Fig.2 Temperature rise vs gas flow rate / nozzle.